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AN

ELEMENTARY TREATISE

ON

CRYSTALLOGRAPHY.

BY

M. V. REGNAULT,

MEMBER OF THE FRENCH ACADEMY OF SCIENCES, AND PROFESSOR AT THE ECOLE POLYTECHNIQUE, ETC., ETC.

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PUBLISHER'S PREFACE.

THE very scanty amount of information upon the crystalline forms of bodies contained in even the larger treatises on chemistry in the English language, has induced the publisher to offer the present translation of Professor Regnault's work to the British public.

Without professing to enter upon the more difficult parts of the science, which would demand of the reader a considerable proficiency in some of the higher branches of mathematics, this elementary treatise gives a clear insight into the principles of the classification of crystals, and fully describes the mode of measuring their angles; a large number of the most common forms are also analyzed and figured, in order to assist the researches of the chemist, and enable him to define, with greater precision, the new bodies that discovery may throw in his way.

The author's name is sufficient guarantee for the excellence of the treatise, and the publisher flatters himself that it will be found a useful if not indispensable appendage to all the larger elementary works upon chemistry. This latter consideration has suggested the expediency of printing it in the octavo form.

London, May, 1848.

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AN ELEMENTARY

TREATISE ON CRYSTALLOGRAPHY.

INTRODUCTION.

§ 1. Of Crystalline Forms.—A superficial view of the solid bodies which come under our observation in nature would tend to encourage the opinion that no regularity existed in their external forms, and that these were susceptible of infinite variation. A more attentive study of these bodies, however, soon renders it evident that they are capable of assuming regular forms under certain circumstances, and that these forms are perfectly similar in different specimens of the same substance. Moreover, the greater number of substances which appear devoid of regular external form, present direct indications on their recently broken surfaces of a regular or crystalline texture; so that the entire mass of these bodies is apparently the aggregation of an infinity of small crystals enveloping each other. These rudimentary crystals are often so small, that they cannot be distinguished without examining the fractured surface with the aid of a magnifier or microscope; whence we may infer that much smaller crystals exist, which altogether escape our means of observation.

The crystalline texture of bodies, far from being an exceptional case, is, on the contrary, much the most general.

The greater number of substances which we prepare in our laboratories are susceptible of *crystallization*, that is to say, of assuming regular geometrical forms; and it is observed that when the formation of these crystals proceeds under the *same circumstances*, the forms of the different individual crystals are precisely similar, so much so, indeed, that these forms are one of the most certain means of distinguishing crystalline bodies from each other. The crystalline forms which different natural substances affect, appear, at first sight, to be infinitely variable; but a minute study of these various forms has brought to light certain general laws to which they are all subject, and which set limits to their number.

The laws relative to the crystalline forms of bodies already occupy a conspicuous place in our chemical theories, and the importance of this branch of study will become still greater, when the science of crystallography is more generally spread, and chemists give themselves the trouble of determining, with precision, the crystalline forms of the bodies which they examine. The principles of this science, which here follow, require merely of the reader an acquaintance with elementary geometry.

§ 2. Crystals are terminated by plane surfaces, and, in general, every plane face, or surface, on the crystal has a corresponding parallel surface, or face, at least when the crystal is isolated and regularly formed throughout. Crystals are very frequently implanted in a solid mass, so that the summit of the crystal is alone visible, and only half the faces can be studied: this renders it difficult, in many cases, to verify the proposition we have just adduced, with reference to the pairs of parallel faces; but there are few imperfect or partially imbedded crystals known, which have not likewise been found isolated and perfect, and the preceding statement can then be verified. We are, therefore, justified, by analogy, in supposing that the same would be the case with all crystals, if they were not implanted in some matrix, and we are, consequently, in the habit of representing them complete in their entire extent.

§ 3. Crystals are always bounded by solid angles, and never by rentrant angles. When the combination of a large number of crystals is examined, for instance the cavities of a rock, the sides of which are covered with crystals, and which mineralogists call a *nest of crystals*, or a crop of crystals, obtained in the laboratory, a number of rentrant angles will be observed, and would appear to negative the above assertion; but

these rentrant angles are produced by the juncture of two distinct crystals, and are never observed on a single isolated individual.

§ 4. CLEAVAGE.—Crystallized bodies are not broken with equal facility in every direction; the fracture generally occurs in the direction of the plane surfaces. These fractures, in the direction of the plane surfaces, may be repeated an indefinite number of times on the same crystal, parallel with each other, so that the crystal may be divided into a number of thin laminæ, with parallel faces; this mode of fracture is termed *lamellar*. The property of crystals just mentioned has long been known to lapidaries, who make use of it in working precious stones. Thus, the diamond presents a lamellar fracture in four different directions; the defective portions of the natural crystal are removed by this mode of fracture, and thus the labour of shaping the diamond is considerably diminished. The operation is called *cleaving the diamond*. Parallel faces obtained in this manner by the fracture of a crystal, are called *cleavages*.

A crystal may present cleavages in different directions, and this is generally expressed by saying, that it presents *several cleavages;* but these are not always obtained with the same ease. Certain cleavages are very easily produced by fracture, even when this is performed at random; others can only be obtained by taking greater precautions; and, again, others are often very imperfect. Thus carbonate of lime presents cleavages in three directions with equal facility, the planes of cleavage are always inclined the one upon the other, at an angle of 105° 5′, the effect of which

is, that the body always breaks in rhombohedral fragments. Sulphate of lime also presents cleavages in three directions; but the fracture is much more easily effected in one direction than in the direction of the other two; the result is, that the crystal has a tendency to separate into lamellæ, which, with the aid of a knife, can be obtained of extreme tenuity. If these lamellæ are broken with the fingers, the other cleavages become apparent, and parallelogrammic forms are obtained.

§ 5. SOLID PRODUCED BY CLEAVAGE, OR PRIMITIVE FORM.—The combination of the planes of cleavage constitute a geometrical solid, which is constant in all individuals of the same crystalline body, this form is termed the solid of cleavage, or the primitive form.

§ 6. EDGES OF CRYSTALS.—The lines in which the planes of crystals intersect, are called the *edges* of the crystal. Edges are distinguished as *obtuse* or *acute*, according as the faces which form the edges produce an obtuse or an acute angle at their point of section.

§ 7. ANGLES OF CRYSTALS.—Three or more faces coming together in one point form a solid angle, which mineralogists simply, but improperly, call an *angle* of the crystal. Angles are classified according to the number of faces by which they are produced: thus, fig. 1 represents a three-faced angle; fig. 2, a four-faced angle; fig. 3, a six-faced angle, &c., &c.

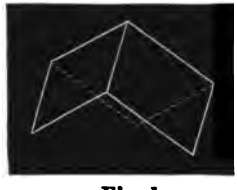

Fig. 1.

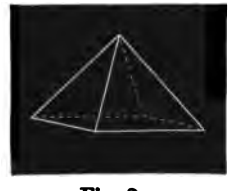

Fig. 2.

Fig. 3.

§ 8. Simple and Compound Forms.—Crystals are sometimes terminated by perfectly similar faces or planes. Such are:—the regular octahedron, formed

Fig. 4.

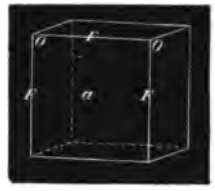

Fig. 5.

Fig. 6.

by eight equilateral triangles (fig. 4); the regular hexahedron or cube, which is terminated by six squares (fig. 5); the hexagonal dodecahedron, formed by twelve isosceles triangles (fig. 6). These forms are called *simple forms*. *Compound forms*, on the contrary, are such as comprise different kinds of faces. Fig. 7

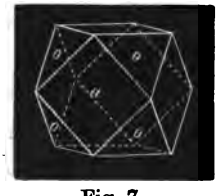

Fig. 7.

represents a compound form; it is constituted of six square faces and eight equilateral triangles. Fig. 8 is also a compound form, bounded by six rectangular faces and twelve isosceles triangles.

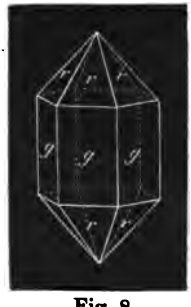

Fig. 8.

If, in a compound form, we imagine the faces of the same kind prolonged in such a manner as to cause the faces of the other kind to disappear, we then obtain a simple form. The triangular faces of fig. 7, when prolonged, would give rise to the regular octahedron (fig. 4). If, on the contrary, the square faces are prolonged, so as

to obliterate the triangular faces, we obtain the hexahedron (fig. 5).

It is thus obvious that the compound forms are derived from the combination of as many simple forms as there are different kinds of faces or planes which bound them; we may, therefore, consider the compound form we have been speaking of (fig. 7), as a combination of the octahedron with the hexahedron.

It often happens that in prolonging the similar faces of a compound crystal, an unlimited form results, which by itself cannot terminate a crystal. Thus, for instance, in supposing the six rectangular faces of fig. 8 prolonged, we obtain a regular prism with six indefinite faces. If, on the contrary, the twelve triangular faces are prolonged, a complete solid is obtained, the hexagonal dodecahedron (fig. 6).

It is clear that the faces which give rise to an unlimited solid, cannot form a crystal by themselves, they are always found in combination, either with faces, which, when prolonged, produce a complete solid, or with faces, which, prolonged, afford open or unlimited forms.

§ 9. PREDOMINANT AND SECONDARY FORMS.—In a compound crystal, one of the simple forms of which it is composed is generally more developed than the others, and gives its general outline to the crystal; this form is then termed the *predominant form*, whilst the other forms which enter into the combination are called *secondary forms*, and their faces are frequently called *modifying faces*. The figs. 9 and 10 both represent

Fig. 9.

combinations of the octahedron with the hexahedron; but in fig. 9 the faces *o* which pertain to the octahedron

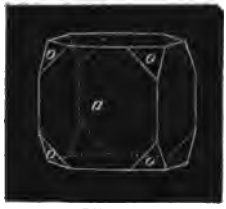

Fig. 10.

are much more developed than the faces *a*, which are those of the hexahedron; so that the crystal presents an octahedral aspect, and its form is described as that of an *octahedron modified by the faces of the cube.* Fig. 10, on the contrary, presents the dominant aspect of the cube, and is described as a *hexahedron modified by the faces of the octahedron.*

§ 10. TRUNCATURES.—When, in a combination of several simple forms, an edge of the dominant form is replaced by a face parallel to that edge, as in fig. 11, the edge is said to be *truncated*, and the modifying face is called the *face* or *facet of truncature of the edge.* This face of truncature may be equally inclined on the two faces of the dominant form, which enclose the truncated edge; the truncature is then said to be right or *tangential:* this is the case in fig. 11. In the contrary case, the truncature is said to be *oblique.*

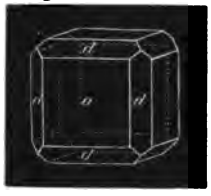

Fig. 11.

The angles of the dominant form are often truncated, and the faces of truncature are *right* or *oblique*, according as the inclinations of these faces towards the faces of the dominant form, which determine the angle, are equal or unequal. Fig. 9 represents a regular octahedron, the angles of which are truncated by the faces of the hexahedron; fig. 10 represents a hexahedron, the angles of which are truncated by the faces of the

octahedron. In both figures the truncatures are right.

When the face of oblique truncature of an angle is equally inclined on the two faces forming one of the edges of that angle, the truncature is said to *rest symmetrically* upon that edge; thus, in fig. 11, the face of truncature is equally inclined on the two faces, and it is said to *rest symmetrically on the edge.* In the opposite case it is said to *rest* obliquely on the edges.

In the same manner, a face of truncature is said to *rest symmetrically on a face* of the dominant form when the line of intersection of these two faces forms equal angles with the two adjacent edges of the dominant face; it is said, on the contrary, to *rest obliquely* on that face when these angles are unequal.

Fig. 12.

§ 11. BEVELMENT.—The edges of the dominant form are frequently replaced by two faces parallel to these edges; in this case, the edge is said to be bevelled. This is seen in fig. 12, where the edges of the hexahedron are bevelled.

§ 12. POINTING.—An angle of the dominant form is often replaced by a more obtuse angle; the angle is then said to be pointed. Sometimes the pointing facets are as numerous as the faces which form the angle as in fig. 13; at other times there are only half as many, as in fig. 14. The pointing facets

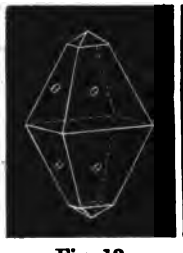

Fig. 13.

Fig. 14.

repose symmetrically, either on the faces (fig. 13), or on the edges of the angle (fig. 14).

§ 13. CENTRE OF THE CRYSTAL.—In every crystal, simple or compound, there exists a point, in passing through which to the faces of the crystal, every straight line is divided into two equal parts. This point is the *centre of the crystal.*

§ 14. AXES OF THE CRYSTAL.—In all simple forms, there exist certain lines passing through the centre of the crystal, about which the faces are disposed symmetrically; these lines are called *axes* of the crystal. Sometimes a crystal comprises several systems of axes, as in the regular hexahedron.

Fig. 15.

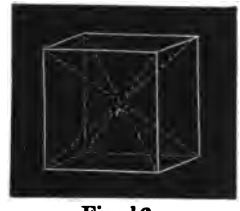

Fig. 16.

If, in fact, the centres of the opposite faces are connected by straight lines (fig. 15), we obtain three lines which exhibit the above relations, and are, consequently, axes; a second system of axes is obtained by joining the opposite angles (fig. 16), this system is composed of four axes, forming with each other an angle of 70° 32′; lastly, if the centres of the opposite edges are united, two and two (fig. 17), we obtain a system of six axes, comprising between each an angle of 60°. All the axes of the hexahedron, which are parts of the same system, are equal to each other.

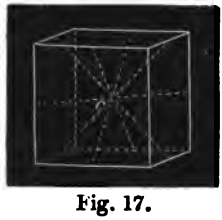

Fig. 17.

In the hexagonal dodecahedron (fig. 18), the axes are obtained by joining the opposite angles; thus a system of three equal horizontal axes, forming an angle of 60° with each other, is obtained, and a single vertical axis perpendicular to the system of the three others.

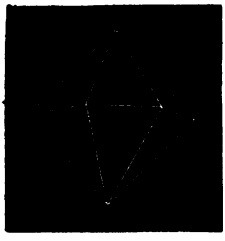

Fig. 18.

In the oblique octahedron with a rhombic base (fig. 19) the axes also consist of lines joining the opposite angles; the axes in this figure are all unequal, and inclined the one upon the other.

Fig. 19.

§ 15. Mode of Placing Crystals.—In order to study with greater facility the various crystalline forms, it is desirable always to place the crystals in a definite fixed position; the custom is to place them in such a manner, that one of their axes shall be vertical: thus, for the hexahedron, that system of axes is usually adopted in which the three axes join the opposite faces of the crystal, cutting each other at right angles. As these three axes are perfectly equal, there can be no choice as to which shall be made the perpendicular, for the figure will present the same aspect in all positions. When, in the system of axes of a crystalline form, there is one axis which stands alone without an analogue in the system, that one is always chosen for placing in the vertical position, and is then called the *principal axis;* the other axes are called *secondary axes.* The hexagonal dodecahedron (fig. 18) is placed

in such a manner, that its single unequal axis shall be in a vertical position.

The octahedron, with a rhombic base (fig. 19), presents three unequal axes, it is evident that any one of these may be chosen as principal axis, and placed in the vertical position; but when once a choice of one of these axes has been made, it is convenient to preserve it as the principal axis during the whole examination of the crystal.

The direction of the secondary axes should, also, not be arbitrary, when the various forms of crystallization of one substance have to be studied. In all the figures of the present work, the crystals will be placed in such a manner, that one of the secondary axes shall be in the direction of the plane of the figure.

§ 16. DEFINITION OF THE SYSTEMS OF CRYSTALS.—The attentive investigation of the various compound forms which occur in the mineral kingdom, has shown that any of the simple forms cannot be combined in the same crystal. *One and the same crystal never comprises other than simple forms derived from the same system of axes.*

Thus we frequently meet with combinations of the cube and the octahedron; in the same manner the rhombohedron is found combined with the regular six-sided prism; but the rhombohedron, or the six-sided prism, is never found in combination with the hexahedron or with the regular octahedron. The rhombohedron and the regular six-sided prism are referable to the same system of axis, consisting of three similar axes situated in the same plane, and forming angles of 60° with each

other, and of a fourth axis perpendicular to the three others; whilst in the cube and the regular octahedron no analogous system of axes is to be found.

The name of *crystalline system* is given to the collection of different forms which are referable to the same system of axes.

Crystallographers have distinguished six systems of crystallization:—

1. The first system, or the regular system, is characterized by three equal axes at right angles to each other;
2. The second system is characterized by three axes at right angles to each other, of which, however, only two are equal;
3. The third crystalline system is distinguished by four axes, of which three are equal, situated in the same plane, and cut each other at an angle of 60°; the fourth axis is of a different kind, and is at right angles to the system of the three others;
4. The fourth crystalline system is characterized by three unequal axes at right angles to each other;
5. The fifth crystalline system is characterized by three unequal axes; two of these axes are obliquely situated towards each other, but the third axis is at right angles to the system of the other two;
6. The sixth system of crystals is characterized by three unequal axes, which are all oblique, the one to the other.

We shall now pass in review the principal crystalline forms which constitute these different systems of crystals.

Isometric

I.—REGULAR SYSTEM.

§ 17. The forms belonging to this system are characterized by three equal axes, disposed at right angles to each other. These forms may be derived from other systems of axes, as we have seen above; but these other systems do not introduce any new points for consideration, and the regular system of crystals is thoroughly defined by the three equal axes at right angles to each other, and this is the only system of axes with which we shall here occupy ourselves.

The principal simple forms belonging to this system are:—

1. The *regular octahedron* (fig. 20) composed of eight equilateral triangles; the edges are all equal; the solid angles are equal, and are formed by four faces. The dihedral angles of the faces are equal to 70° 32′.

Fig. 20.

The axes join the opposite angles of the crystal, and are at right angles to each other, and each face cuts off equal parts of the three axes. It follows from this, that if a represent that portion of these axes comprised between the centre of the crystal and the point where they meet the faces, the face of the octohedron may be defined in saying that it is the face which cuts the three axes at right angles to each other at equal distances a. It is usual to represent this face by the formula

$$(a : a : a)$$

which expresses the condition of equality between the three axes.

2. The *hexahedron* or *cube* (fig. 21) is formed by six square faces; the three axes join the centres of the opposite faces, each face is perpendicular to one of the axes and parallel to the other two, so that each of these faces, and, consequently, the entire hexahedron may be represented by the formula

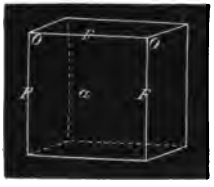

Fig. 21.

$$(a : \infty a : \infty a).$$

3. The *dodecahedron* (fig. 22), formed by twelve rhombic faces, the angles of which are 109° 28′ and 70° 32′.

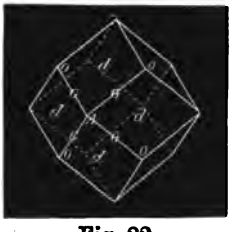

Fig. 22.

The angles are of two kinds, six angles A produced by four faces, and corresponding in position to the angles of the octahedron, and eight tri-facial angles *o* corresponding to the angles of the hexahedron. Each face of the dodecahedron is parallel to one octahedral axis, and cuts the other two at equal distances; these faces may be represented by the formula

$$(a : a : \infty a).$$

4. The *tetrahedron* (figs. 23 and 24) formed by four faces of equilateral triangles. This solid may be derived from the regular octahedron, by supposing the

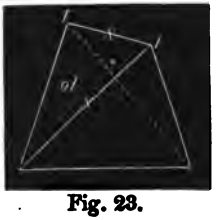

Fig. 23.

Fig. 24.

alternate faces of the octahedron, prolonged in such a manner as to cause the disappearance of the intermediate faces. According as the one or other system of alternate faces is obliterated, one or other of the tetrahedrons (figs. 23 and 24) is obtained; the two coincide perfectly, and are only distinguished from each other by their position.

This mode of explaining the formation of the tetrahedron has given rise to the denomination *hemi-octahedron.*

5. *Tetrakishexahedron,* or *pyramidal hexahedron* (fig. 25), is a solid with twenty-four faces; it has the general aspect of a hexahedron, upon the faces of which quadri-facial pyramids have been placed.

Fig. 25.

In most cases the height of the quadri-facial pyramids which are implanted upon the faces of the hexahedron is equal to the half of the axis of the hexahedron. Sometimes, however, the relation between the height of the pyramids and the axis of the hexahedron is more complex, but it is always represented by a very simple rational fraction. Thus, the relations are often $\frac{2}{3}$, $\frac{2}{5}$, $\frac{1}{3}$, $\frac{1}{5}$.

Fig. 26.

If the alternate faces of the tetrakishexahedron are imagined prolonged, so as to obliterate the intermediate faces, a solid is obtained with twelve pentagonal faces, the *pentagonal dodecahedron* (fig. 26), which may also be called the *hemi-tetrakis-*

hexahedron on account of the mode of its formation. It is obvious that the same tetrakishexahedron may afford two hemi-tetrakishexahedrons, according as the one or other system of alternate faces is prolonged. These two forms will coincide perfectly, and only differ from each other in the direction of their faces.

6. The *trisoctahedron*, or *pyramidal octahedron* (fig. 27), is a solid, with twenty-four faces, presenting the general aspect of the octahedron, upon the faces of which, however, tri-facial pyramids are superposed.

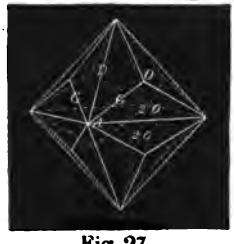

Fig. 27.

As there exist several tetrakishexahedrons presenting different relations with reference to the height of the pyramids and the length of the axes, so are there several trisoctahedrons; the relations between the height of the pyramids and the axes are always represented by very simple fractions, as, for instance, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{3}$.

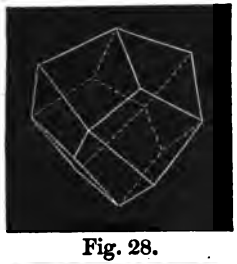

Fig. 28.

On prolonging the alternate faces of the trisoctahedron, a hemihedral solid is obtained, the hemitrisoctahedron (fig. 28), but this form is of very rare occurrence.

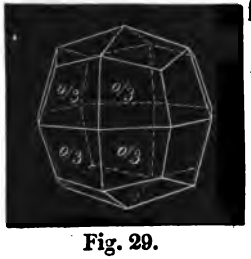

Fig. 29.

7. The *icositetrahedron* (fig. 29) is a solid with twenty-four faces, forty-eight edges, and twenty-six angles. This form is obtained by imagining the solid angles of the regular octahedron replaced by more obtuse quadri-facial pyramids, as is shown in

figure 30, and by subsequently prolonging the faces of these pyramids so as to obliterate completely the faces of the octahedron. The relation between the height of these pyramids and the length of the axes of the octahedron may be different, so that there may exist several icositetrahedrons; but this relation is always represented by a very simple rational fraction; the only relations as yet known are $\frac{1}{2}$ and $\frac{1}{3}$.

Fig. 30.

The icositetrahedrons are rarely met with amongst crystals, and are merely mentioned on the present occasion.

§ 18. Compound Forms of the Regular System.—The simple forms which we have just enumerated, give rise, in combining with each other, to a great number of compound forms, the chief of which we shall now notice.

Figures 31, 32, 33, represent three combinations of the regular octahedron with the hexahedron, in which the faces of the octahedron are marked *o*, and those of the hexahedron are marked *a*.

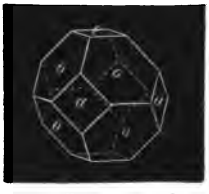

Fig. 31.

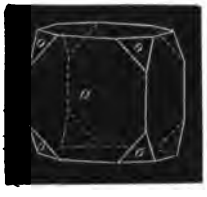

Fig. 32.

Fig. 33.

In fig. 31 the faces of the octahedron are predominant; the contrary is the case in fig. 32; and lastly, in

fig. 33, the two forms are equally developed; this latter combination is known as the *cubo-octahedron.*

The figs. 34 and 35 represent the combinations of the dodecahedron with the octahedron. In fig. 35 the faces of the octahedron *o* are predominant, whilst in fig. 34 the predominant faces are the faces *d* of the dodecahedron.

Fig. 34.

Fig. 35.

In fig. 36 we have a combination of the hexahedron with the dodecahedron, in which the faces *a* of the hexahedron are predominant.

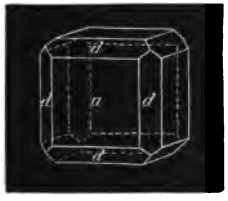

Fig. 36.

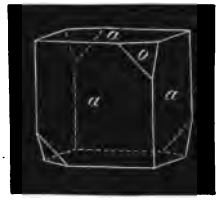

Fig. 37.

Fig. 37 represents a combination of a predominant hexahedron with the tetrahedron; it will be seen that of the eight solid angles of the hexahedron, four only are truncated by the faces *o* of the tetrahedron or hemi-octahedron. In this combination we find an exception to the law stated in § 2; which was to the effect, that in every crystal terminated regularly over its whole surface, each face of the crystal had always a face parallel to it. In the combination of the hexahedron with the tetrahedron, the facets *o* of the tetrahedron are not parallel with any facets on the opposite angles of the hexahedron.

Fig. 38 represents a combination of the two tetra-

hedrons obtained by prolonging the two alternate systems of faces of the same octahedron.

Fig. 38.

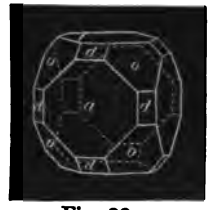

Fig. 39.

The preceding forms result from the union of two simple forms only of the regular system, but compound forms are sometimes met with, which result from the combination of three or a larger number of simple forms. Thus Fig. 39 represents a combination of the predominant hexahedron *a* with the octahedron *o* and the dodecahedron *d*.

Fig. 40.

Fig. 40 is a combination of the predominant hexahedron *a* with the dodecahedron *d* and the tetrahedron *o*.

II.—SECOND SYSTEM OF CRYSTALS. (Tetragonal)

§ 19. The forms which belong to this system are characterised by three axes at right angles to each other, two of which are equal, and the third is unequal. The third unequal axis is chosen as the principal axis, and the crystal is placed and regarded with this axis in a vertical position. The relations of length between the principal axis and the secondary axes appears to vary without limit; in general these relations are complex and irregular.

In the regular system of crystals, the three axes were equal, and it followed from this that the faces were disposed in a perfectly symmetrical manner with

reference to the axes. This is not the case in the second crystalline system, the two secondary axes being equal, the faces are disposed symmetrically with reference to those faces, but the faces are disposed differently with reference to these than they are with reference to the principal axis. Faces are also met with in this system at right angles to the principal axis which have no analogues as regards the secondary axes; in the same manner there are faces at right angles to the two secondary axes which have not necessarily any analogue on the principal axis. These faces thus produce open prisms which alone cannot terminate a crystal. Nothing of a similar nature can possibly occur in the regular system.

SIMPLE FORMS OF THE SECOND SYSTEM OF CRYSTALS.—*Octahedrons with square base* (fig. 41). The

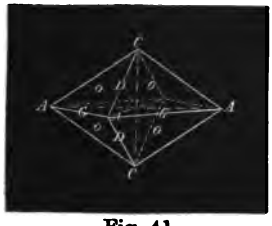

Fig. 41.

faces of these octahedrons are isosceles triangles; their edges are of two kinds: eight terminal edges D which converge towards the principal axis C C and four lateral edges G. The section which passes through the lateral edges, and consequently through the secondary axes, affords a square (fig. 41*a*); this section is called the

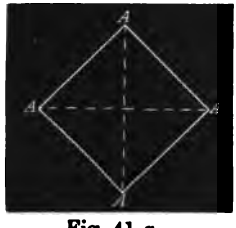

Fig. 41 *a*.

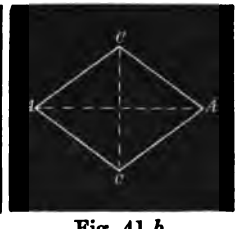

Fig. 41 *b*.

base of the octahedron. The sections through the terminal edges afford rhombs (fig. 41*b*). In the regular system of crystals

there was only one octahedron; in the second system, on the contrary, there is an innumerable number of octahedrons with square base, which differ from each other in the inclinations of their faces, or by the relative lengths of the principal axis, and of the two equal secondary axes; and, in order to distinguish any particular octahedron, it is necessary to indicate this relation of length, or to define the inclination of the faces.

In all the octahedrons of the second system, the principal axis always joins the two summits of the octahedron, but the secondary axes may present two different positions with reference to the lateral edges of the octahedron, or to the sides of the base. These axes may join the opposite angles of the base,

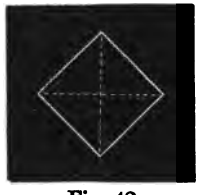

Fig. 42.

Fig. 43.

as in fig 42, or they may unite the opposite sides, as in fig. 43. In fact, two octahedrons with square bases are thus obtained with a perfectly equal system of axes; the octahedron, with a base similar to fig. 43, has its faces inclined precisely in the same manner as the edges of the octahedron, with a base like fig. 42, are inclined. These two are distinguished by calling the octahedron with a base like fig. 42, the *octahedron of the first class*, or *direct octahedron;* and the octahedron with a base like fig. 43, the *octahedron of the second class*, or *reversed octahedron.* When a substance crystallizes in the form of an *octahedron with a square base*, it does not always assume precisely the same form of octahedron. On the con-

trary, several different octahedrons are frequently observed, which, however, stand in a very simple relation to each other. This relation may be defined as follows:—*If the octahedrons are reduced, so as to have the same bases, their heights, or their principal axes will present a rational and very simple relation to each other.*

One of these octahedrons is chosen as the *principal* or *primitive form;* the preference is given to that one which is most frequently met with, or to that which predominates in the combinations. To this principal or primitive form the following notation is applied:—

$$(a : a : c).$$

The formula for all the octahedrons in which the base is placed in the same position with reference to the secondary axes, that is to say, for all the octahedrons of the first class, or direct octahedrons, will therefore be

$$(a : a : mc);$$

whilst that for the octahedrons of the second class, or reversed octahedrons, in which the inclination of the faces is equal to that presented by the edges of the corresponding octahedrons of the first class, will be

$$(a : \infty a : mc).$$

If an unlimited number of arbitrary values is ascribed to m, then the number of the octahedrons will be infinite; but observation has shewn that in the various octahedrons with a square base, presented by the same substance, the number m is always a rational and very simple value; thus, the notation of the primitive octahedron being

$$(a : a : c),$$

we never find in the same substance a greater number of octahedrons, than are expressed by the formulæ:—

$$\begin{array}{ll} (a:a:2c) & \text{or } (a:a:\tfrac{1}{2}c) \\ (a:a:3c) & (a:a:\tfrac{1}{3}c) \\ (a:a:4c) & (a:a:\tfrac{1}{4}c); \end{array}$$

that is to say, octahedrons, in which the secondary axes being equal, the principal axis is 2, 3, 4 times greater, or 2, 3, 4 times less than the principal axis c of the primitive octahedron.

Octahedrons of the second class also occur, as expressed by the following formulæ:—

$$\begin{array}{ll} (a:\infty a:c) & \text{or } (a:\infty a:c) \\ (a:\infty a:2c) & (a:\infty a:\tfrac{1}{2}c) \\ (a:\infty a:3c) & (a:\infty a:\tfrac{1}{3}c) \\ (a:\infty a:4c) & (a:\infty a:\tfrac{1}{4}c). \end{array}$$

There are, however, still two cases which frequently occur in substances belonging to the second system of crystals, they are those which may be deduced from the formulæ

$$a:a:mc$$
$$a:\infty a:mc$$

by making

$$m = 0$$
$$\text{or } m = \infty.$$

Right Terminal Face.—In according gradually diminishing values to m, we obtain more and more flattened octahedrons, and at last, when $m = 0$, the octahedron is reduced to its base, we call this limit to the form of the octahedron the *right terminal face.* This terminal face can never occur isolated, but it is

very frequently met with in combination in compound forms. The notation for this face might be $(a : a : 0c)$; but it is generally expressed by $(\infty a : \infty a : mc)$, or simply $(\infty a : \infty a : c)$; it is, therefore, considered as the boundary of the octahedrons with a principal axis mc, in which, however, the secondary axes, without ceasing to be equal, have become infinite.

PRISMS WITH SQUARE BASE.—In according gradually increasing values to m in the general formulæ $(a : a : mc)$, $(a : \infty a : mc)$, we obtain more and more acute octahedrons; and, lastly, when $m = \infty$, the octahedrons are converted into two square-based prisms, the bases of which are represented in fig. 42 for the prism derived from the octahedrons of the first class, and in fig. 43 for the prism which constitutes the limit to the octahedrons of the second class. These two prisms are incapable by themselves of forming the boundary of a crystal; in combination with the octahedrons or with the right terminal face, however, they frequently make up a crystal.

§ 20. COMPOUND FORMS OF THE SECOND CRYSTALLINE SYSTEM.—When the two primitive octahedrons of the first and second class enter into combination with each other, the octahedron of the second class d forms right truncatures on the edges of the octahedron of the first class o, as in fig. 44, which also exhibits the right terminal face c.

Fig. 44.

Fig. 45.

Fig. 45 represents a combination of the primitive

octahedron *o*, expressed by the formula $(a : a\ c)$, with the obtuse octahedron of the same class $\frac{o}{3}$, expressed by the formula $(a : a : \frac{1}{3}c)$, and with the more acute octahedron $2d$ of the second class $(a : a\ 2c)$.

Fig. 46 shows a combination of the primitive octahedron *o*, $(a : a : c)$, with the right prism of the same class *g*, $(a : a : \infty c)$.

Fig. 47 represents a combination of the same primitive octahedron *o*, $(a : a : c)$, with the right prism of the second class *a*, $(a : \infty a : \infty c)$.

Fig. 46.

Fig. 47.

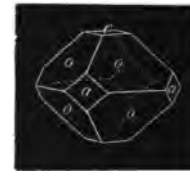

Fig. 48.

In Fig. 48 we find a combination of the primitive octahedron *o*, $(a : a : c)$, with the right terminal face *c*, and with the prism of the second class *a*, $(a : \infty a : \infty c)$; the primitive octahedron being predominant in the compound form.

Fig. 49.

Fig. 50.

Fig. 49 represents a combination of two right prisms *g* and *a*, expressed by the formulæ $(a : a : \infty c)$, $(a : \infty a : \infty c)$, with the primitive octahedron *o*, $(a : a : c)$, and the corresponding octahedron of the

second class *d*, $(a : \infty a : c)$; the predominant form being that of the right prism $(a : a : \infty c)$.

Lastly, in fig. 50, we have a combination of the primitive octahedron *o*, $(a : a : c)$, with the acute octahedron of the same class 3, $(a : a : 3c)$, and the right prism of the second class *a*, $(a : \infty a : \infty c)$. The prism is predominant in the combination.

III.—THIRD SYSTEM OF CRYSTALS.

§ 21. The forms which are referable to the third system of crystals are characterized by four axes, three of which are equal, and cut each other at an angle of 60°, the fourth axis is of a different kind, and is at right angles to the three others. This axis is selected as the principal axis, and the three like axes are consequently secondary. The relation between the length of the principal axis and that of the secondary axes is variable.

It is evident that, in this system of crystals, the faces are symmetrically placed, with reference to the three secondary axes; whilst their position, as regards the principal axis, is altogether different. Indefinite forms occur in the third system as well as in the second, and in all those systems which follow, which in themselves are incapable of bounding a crystal.

Fig. 51.

The following are the principal simple forms which occur in this system:

Hexagonal (*Dodecahedrons*) (fig. 51).—These forms present twelve faces, eighteen edges, and eight angles.

The faces are isosceles triangles.

The edges are of two kinds; twelve terminal edges D, and six lateral edges G.

The angles are also of two kinds; two terminal angles C, which are regular and formed by six faces, and six lateral quadri-facial angles which are simply symmetrical.

A section through the lateral edges gives the *base* of the crystal, which is a regular hexagon, and includes the three secondary axes. Sections passing through two parallel lateral edges afford rhombs.

Two classes of dodecahedrons may be distinguished, according to the manner in which the secondary axes are placed with reference to the sides of the base. In the first class, the axes join the angles of the base, as in fig. 52. In the second class the axes join the middles of the opposite sides, as in fig. 53.

Fig. 52.

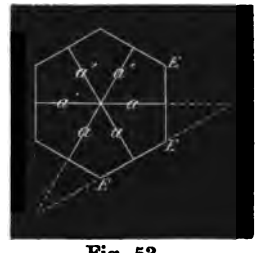

Fig. 53.

The faces of the dodecahedrons of the first class, or direct dodecahedrons, cut off equal lengths a from two of the secondary axes, and are parallel to the third.

The faces of the corresponding dodecahedrons of the second class, or reversed dodecahedrons, cut a portion $= a$ from one only of the secondary axes, and if prolonged would cut the other two axes at distances $= 2a$.

The formula for dodecahedrons of the first class will consequently be

$$(a : a : \infty a : c)$$

Whilst that for the corresponding dodecahedrons of the second class is:—

$$(2a : a : 2a : c).$$

Besides the two dodecahedrons of which we have just made mention, there may exist an infinity of others belonging to either class, of which the general formula will be:—

$$(a : a : \infty a : mc) \qquad (2a : a : 2a : mc).$$

In one and the same substance, however, the dodecahedrons always present a very simple relation. *If these dodecahedrons are referred to systems of secondary axes that are equal, their principal axes will present amongst themselves very rational and simple relations, the values of m will be* 2, 3, 4 or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$.

One of these dodecahedrons is chosen as the *principal* or *primitive form,* and the preference is given to that which is of the most frequent occurrence, or to that which generally predominates in compound forms. In according the formula:—

$$(a : a : \infty a : c)$$

to the primitive form, the formulæ for the dodecahedrons will be:—

Dodecahedrons of the same class.	Dodecahedrons of the second class.
$(a : a : \infty a : 2c)$	$(2a : a : 2a : c)$
$(a : a : \infty a : 3c)$	$(2a : a : 2a : 2c)$
$(a : a : \infty a : 4c)$	$(2a : a : 2a : 3c)$
$(a : a : \infty a : \frac{1}{2}c)$	$(2a : a : 2a : 4c)$
$(a : a : \infty a : \frac{1}{3}c)$	$(2a : a : 2a : \frac{1}{2}c)$
$(a : a : \infty a : \frac{1}{4}c)$	$(2a : a : 2a : \frac{1}{3}c)$
	$(2a : a : 2a : \frac{1}{4}c)$

Indefinite forms are, however, frequently met with

which may be viewed as limits to the dodecahedral form, and are obtained by making $m = 0$, or $m = \infty$ in the general formulæ

$$(a : a : \infty a : mc) \qquad (2a : a : 2a \,.\, mc).$$

In making $m = 0$ in these formulæ, the dodecahedrons are reduced to a single face parallel and similar to the base. We call this the *right terminal* face. The notation for this face will then be $(a : a : \infty a : 0c)$; but its formula is generally written $(\infty a : \infty a : \infty a : mc)$ that is, this face is considered the limit to the hexagonal dodecahedrons having *mc* as their principal axis, whilst the secondary axes, without ceasing to be equal, are supposed to become endless.

On making $m = \infty$ two six-sided prisms are obtained, with the formulæ:—

$$(a : a : \infty a : \infty c)$$
$$(2a : a : 2a : \infty c)$$

Rhombohedrons or hemi-dodecahedrons (fig. 54). The rhombohedrons have six faces, twelve edges, and eight angles. The faces are rhombs; the edges are of two kinds, six terminal edges X, and six lateral edges. The angles are also of two kinds: two angles C, which are tri-facial and regular, and six lateral angles E, which are also tri-facial but irregular.

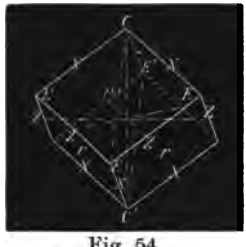

Fig. 54.

The principal axis connects the two terminal angles C, whilst the secondary axes connect the centres of the opposite lateral edges. Sections passing through the

two oblique diagonals CE, C′E′ are rhombs, the planes of which are perpendicular to the faces of the rhombohedron to which these diagonals belong. There are three sections of this kind in a rhombohedron, and they are called the *principal sections* of the rhombohedron.

The rhombohedron may be regarded as derived from the hexagonal dodecahedron, in a manner similar to that by which the tetrahedron was obtained from the regular octahedron, *i.e.* by imagining the alternate faces of the dodecahedron so much developed as to obliterate the intermediate faces; the parallel faces of the dodecahedron will then only remain. But as either the one or other system of alternate faces may be prolonged, it is clear that we can obtain two rhombohedrons (fig. 54 and 55) which are perfectly equal, and which, if the one were turned round 60° with reference to its principal axis, might be confounded with each other. We shall call these two rhombohedrons respectively, *rhombohedron of the first class*, and *rhombohedron of the second class;* or again *direct rhombohedron and reversed rhombohedron.*

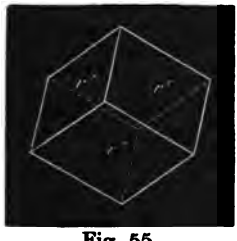

Fig. 55.

The faces of the rhombohedron coinciding with the faces of the hexagonal dodecahedron will be obviously denoted by the same formulæ as the faces of the dodecahedron; for the sake of distinguishing these latter, however, the co-efficient $\frac{1}{2}$ is appended to their formulæ. Thus the notation for the rhombohedrons of the first class will be

$$\tfrac{1}{2}\,(a : a : \infty a : mc),$$

and that for the rhombohedrons of the second class will be

$$\tfrac{1}{2}(a' : a' : \infty a : mc).$$

An accent is given to the first two axes in this latter formula, in order to express that the rhombohedrons of the second class will, when prolonged, cut those axes which are cut directly by the rhombohedrons of the first class.

The same substance, crystallizing in forms, belonging to the third system of crystals, often assumes the form of several rhombohedrons of the first and of the second class. *Supposing the secondary axes of these rhombohedrons to be equal, it is found that the lengths of the principal axes are in rational and very simple proportions to each other*, as is the case also with the dodecahedrons of the same system. One of these rhombohedrons is generally chosen as the primitive form, and all the others are compared with it.

Rhombohedrons, the faces of which are in the same position as the faces of the principal rhombohedron, are considered as belonging to the first class; the second class, on the contrary, comprises all those, the faces of which are in the position of the edges of the principal rhombohedron.

The rhombohedrons offer a series of more obtuse or acute figures, as was the case with the octahedrons of the second crystalline system. Each obtuse rhombohedron of this series has its faces inclined towards the principal axis in the same manner as the edges of the acute form which immediately follows it; so that each figure is the *first acute rhombohedron* of that which precedes it, and *the first obtuse* rhombohedron of that

which follows. The forms which follow each other immediately in these series belong to different classes. The rhombohedrons which form these series are denoted in the following manner:—

Principal rhombohedron	$(a : a : \infty a : c)$
1st obtuse rhombohedron	$(a' : a' : \infty a : \frac{1}{2}c)$
2nd „ „	$(a : a : \infty a : \frac{1}{4}c)$
3rd „ „	$(a' : a' : \infty a : \frac{1}{8}c)$
1st acute rhombohedron	$(a' : a' : \infty a : 2c)$
2nd „ „	$(a : a : \infty a : 4c)$
3rd „ „	$(a' : a' : \infty a : 8c)$.

Other rhombohedrons sometimes occur, in which the principal axes are equal to three or to five times the principal axis of the primitive rhombohedron. The third system of crystals comprises likewise some other more complex simple forms: a solid with twenty-four faces consisting of scaline triangles, and which has received the name of *didodecahedron*, and a solid with twelve faces, also scaline triangles, which is hemihedral to the former, and is called *hemi-didodecahedron* or *scalenohedron*. It is not our object to dwell upon these forms which seldom occur among crystals.

§ 30. Compound Forms of the Third System.—We shall notice in the next place a few of the compound forms of the third system.

Fig. 56.

Fig 56 represents a combination of the primitive dodecahedron, with the first six-sided prism *g*.

Fig. 57.

Fig. 57 represents a combination of the

principal rhombohedron r, denoted by the formula $\frac{1}{2}(a : a : \infty a : c)$, with its first obtuse rhombohedron $\frac{r'}{2}$, the notation for which is $\frac{1}{2}(a' : a' : \infty a : \frac{1}{2}c)$, this latter dodecahedron $\frac{r'}{2}$ being the predominant form.

Fig. 58 represents a combination of the principal rhombohedron r

$$\tfrac{1}{2}(a : a : \infty a : c)$$

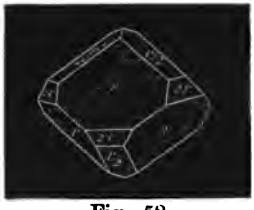

Fig. 58.

with its first obtuse rhombohedron $\frac{r'}{2}$

$$\tfrac{1}{2}(a' : a' : \infty a : \tfrac{1}{2}c)$$

and with its first acute rhombohedron $2r$

$$\tfrac{1}{2}(a' : a' : \infty a : 2c),$$

the rhombohedron r being the predominant form.

Fig. 59 represents a combination of the primitive rhombohedron

$$\tfrac{1}{2}(a : a : \infty a : c)$$

with its second acute rhombohedron $4r$

$$\tfrac{1}{2}(a : a : \infty a : 4c),$$

the latter rhombohedron $4r$ predominating.

Fig. 60 represents a combination of the first six-

Fig. 59.

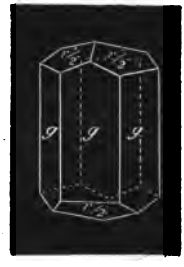

Fig. 60.

Fig. 61.

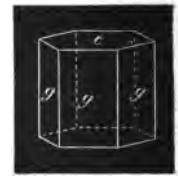

Fig. 62.

sided prism g with a rhombohedron $\frac{r'}{2}$ of the second class.

Fig. 61 exhibits a combination of the principal rhombohedron *r*, with the second six-sided prism *a*.

Lastly, Fig. 62 represents a combination of the six-sided prism *g* with the terminal face *c*.

IV. FOURTH SYSTEM OF CRYSTALS.

§ 23. The forms of the fourth crystalline system are distinguished by three rectangular axes, which are all unequal, and of different kinds; it is, therefore, evident that the selection of the principal axis must be perfectly arbitrary. The relations of length between the three axes follow no law, and are, in general, irrational.

The forms which occur in this system are the following:—

SIMPLE FORMS.—*Right Octahedrons with rhombic base* (fig. 63). The faces of these octahedrons are scaline triangles. The edges are of three kinds; four terminal edges D which connect the extremities of the principal axis with those of the first secondary axis, four terminal edges F which connect the extremities of the principal axis and those of the second secondary axis, and four lateral edges G which connect the extremities of the secondary axes with each other.

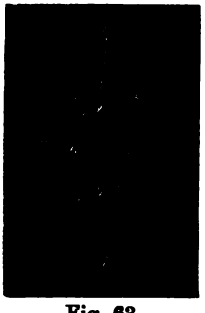

Fig. 63.

The angles are also of three kinds: two terminal angles C situated at the extremities of the principal axis, two lateral angles A at the extremities of the first secondary axis, and two lateral angles B at the extremities of the second secondary axis.

Sections made through the terminal edges yield rhombic planes (figs. 64 and 65); the same figure is produced by a section through the lateral edges, which also forms the *base* (fig. 66).

Fig. 64.

Fig. 65.

Fig. 66.

When the same substance affects the form of different octahedrons with rhombic base, all the octahedrons present simple relations as regards the length of their axes.

The formula or the primitive form is

$$(a : b : c).$$

The other octahedrons which occur with the same substance will then be expressed by the following formulæ:—

$$\begin{array}{l} (\ a\ :\ b\ :mc) \\ (\ a\ :mb:\ c\ ) \\ (ma:\ b\ :\ c\ ) \\ (ma:nb\ :\ c\ ) \end{array}$$

m and n being very simple rational numbers.

The three first formulæ may be considered as particular cases of the fourth.

The number of octahedrons of the fourth system which *can* occur with one and the same substance is

still greater than was the case in the second system of crystals. But, in reality, this number is *very limited*, and other octahedrons than those expressed by the following formulæ are rarely met with:—

$$\begin{array}{ll} (a : b : c) & \\ (a : b : \tfrac{1}{2}c) & (a . b : 2c) \\ (a : b : \tfrac{1}{3}c) & (a : b : 3c) \end{array}$$

together with the limiting forms, obtained by supposing m and n equal to zero or to infinity in the general formulæ.

In making m or n equal to zero, the octahedron is reduced to a single face, perpendicular to one of the axes of the crystal. We thus obtain:—

1st. A face perpendicular to the principal axis, by making $c = 0$; the notation for this face ought then to be $(ma : nb : oc)$, it is, however, generally expressed by the formula $(\infty a : \infty b : c)$ which supposes it derived from the octahedrons $(ma : nb : c)$ having the axis C, but in which the secondary axes are supposed to have become endless.

2nd. A face at right angles to the first secondary axis, obtained by supposing $a = 0$; the notation for this face ought then to be $(0a : mb : nc)$; it has received the formula $(a : \infty b : \infty c)$; *i. e.* it is supposed derived from the octahedrons $(a : mb : nc)$ in which the secondary axis a exists, but in which the axes b and c have become endless.

3rd. A face at right angles to the second secondary axis, obtained by making $b = 0$; this will then be denoted by $(ma : 0b : nc)$; but the formula usually assigned it is $(\infty a : b : \infty c)$: this face is then regarded

as the limit to the octahedrons having the axis b, and in which the axes a and c have become infinite.

In making m or n equal infinity in the general formulæ, three systems of prisms are obtained, the edges of which are parallel to each of the three axes:—

1st. A first system, comprising the vertical prism, the faces of which are parallel to the principal axis; their general formula is $(a : mb : \infty c)$; their base is the same as that of the octahedron from which they are derived. The vertical prism derived from the primitive octahedron is denoted by $(a : b : \infty c)$.

2nd. A second system comprising the horizontal prisms, the faces of which are parallel to the first secondary axis, the general formula for which, is $(a : \infty b : mc)$; the prism derived from the primitive octahedron is expressed by the formula $(a : \infty b : c)$.

3rd. The third system comprises the horizontal prisms, the faces of which are parallel to the second secondary axis; their general formula is $(\infty a : mb : c)$ and that of the prism derived from the primitive octahedron is $(\infty a : b : c)$.

§ 24. Compound Forms.—The principal compound forms which occur in this system are the following:—

(Fig. 67.) A combination of the principal octahedron o with the more obtuse octahedron $\frac{o}{3}$, the terminal face c and the second horizontal prism f of the principal octahedron.

(Fig. 68.) A combination of the principal octahedron o with its vertical prism g, and the vertical prism $\frac{g}{2}$.

(Fig. 69.) A combination of the principal octahedron o with its first horizontal prism d and the vertical prism $\frac{g}{2}$.

(Fig. 70.) A combination of the vertical prism *g* of the primitive form, with the second horizontal prism *f*

Fig. 67.

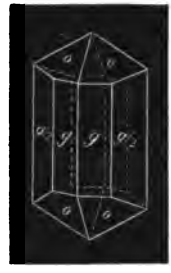
Fig. 68.

Fig. 69.

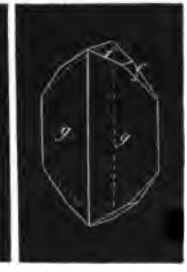
Fig. 70.

of the primitive form, and with a second more acute horizontal prism $2f$.

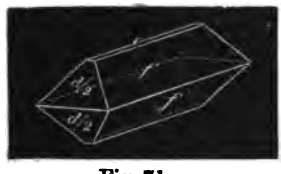
Fig. 71.

Fig. 72.

(Fig. 71.) A combination of the second horizontal prism of the primitive form, with the first horizontal prism $\frac{d}{2}$ and the right terminal face *c*.

(Fig. 72.) The same combination with the terminal face predominant.

(Fig. 73.) A combination of the first vertical prism *g* of the primitive form, with the right terminal face *c*; the terminal face being predominant.

Fig. 73.

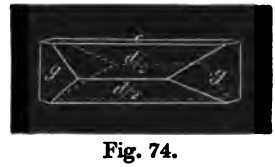
Fig. 74.

(Fig. 74.) A combination of the vertical prism *g* of

the primitive form, with the first horizontal prism $\frac{d}{2}$ and the terminal face *c*.

Fig. 75.

(Fig. 75.) A combination of the principal octahedron *o*, with the lateral faces *a* and *b*.

Monoclinic

V. FIFTH SYSTEM OF CRYSTALS.

§ 33. The fifth system of crystals is characterized by three axes, which are all three unequal; two of these axes are oblique to each other, the third is at right angles to the other two. The relations of length between these axes are variable without limit, and generally irrational.

Fig. 76 represents an octahedron belonging to this system; one of the oblique axes is chosen as the principal axis *c*. The faces are scaline triangles, but they are of two kinds.

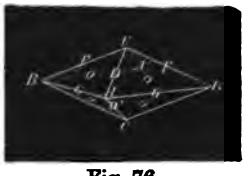

Fig. 76.

The edges are of four kinds; four terminal edges which connect the axes *a* and *c*; the opposite edges are the only edges that are equal to each other on account of the obliquity of the axes; four terminal edges which connect the axes *b* and *c*, and which are all equal, because the two axes *b* and *c* are perpendicular to each other: and, lastly, four lateral edges which connect the perpendicular axes *a* and *b*, and which are, consequently, equal to each other.

The section passing through the edges D, D′ is a parallelogram (fig. 77) which encloses the two oblique axes, it is called the *principal section*. The section

through the lateral edges forms the *base* of the octahedron, and is a rhomb (fig. 78).

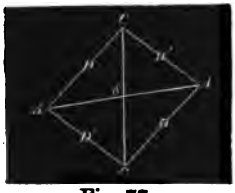

Fig. 77.

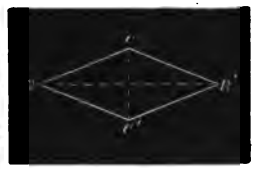

Fig. 78.

In order to define the octahedron thoroughly, it is not sufficient to give the lengths of the three axes, but the value of the angle δ, formed by the two oblique axes b and c, must also be denoted.

The octahedron of the fifth system is not enclosed by equal faces; it is consequently, properly speaking, not a *simple form*. It may be viewed as a combination of two oblique prisms, the first of which is formed by the faces BAC, CAB′, BA′C′ and C′A′B′, and the second by the faces BCA′, CA′B′, BAC′, CA′B′. These two prisms may be distinguished by calling the first the *oblique prism anterior to the octahedron;* and the second, the *oblique prism posterior to the octahedron.* This distinction is necessary, as it frequently happens that, in compound forms of this system, the octahedrons are not perfect, but only one of their oblique prisms occurs; at other times the one of these prisms predominates very much over the other.

The values of the axes a, b, c, being capable of infinite variation, as well as the value of the angle δ, it is obvious that the fifth system must comprise an infinity of different octahedrons. But when one and the same substance presents, amongst its crystalline forms, several octahedrons belonging to the fifth system, it has been observed that in all these octahedrons the angle δ is the same, and that the lengths of the

axes a, b, c of one of these octahedrons always exhibit *commensurable*, and generally *very simple* relations with the lengths of the corresponding axes in all the others. So that if one of these octahedrons is chosen as a standard of comparison, and is denoted by $(a : b : c)$, all the octahedrons occurring in the same substance will be comprised under the general formula

$$(ma : nb : pc),$$

the quantities m, n, p being rational numbers, commensurable and generally very simple, as, for instance, 2, 3, 4.... or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$....

The forms which occur most frequently in this system, are the limiting forms, obtained by making successively $m = \infty$, $n = \infty$, $p = \infty$, or, by supposing $m = 0$, $n = 0$, $p = 0$, in the general formula.

When $p = \infty$, vertical prisms are obtained, parallel to the principal axis c, the general formula for these may be expressed by

$$(a : mb : \infty c),$$

the notation for the principal prism will be

$$(a : b : \infty c).$$

By making $n = \infty$, horizontal prisms are obtained parallel to the second secondary axis b, the general formula for which is

$$(a : \infty b : mc),$$

that for the principal horizontal prism being

$$(a : \infty b : c);$$

lastly, when $m = \infty$, we obtain oblique prisms parallel to the secondary axis a, the general formula for which is

$$(\infty a : b : mc),$$

the principal oblique prism having the formula

$$(\infty a : b : c).$$

When $p = 0$, a terminal face is produced parallel to the axes a and b, to which the notation $(ma : nb : oc)$ may be applied, but it is generally expressed by the formula $(\infty a : b : \infty c)$; this face is then regarded as the limit to the octahedrons $(ma : b : pc)$ having the secondary axis b, the axes ma and pc being infinite.

When $n = o$, we obtain a terminal face parallel to the axes a and c, the formula for which will be $(ma : 0b : pc)$; it is, however, generally expressed by the formula $(\infty a : b : \infty c)$: this face is viewed as the limit to the octahedrons $(ma : b : pc)$ with the secondary axis b, whilst the axes ma and pc have become infinite.

Lastly, if $m = 0$, we obtain a terminal face, parallel to the axes b and c, which may be denoted by the formula $(0a : nb : pc)$; but is generally expressed by $(a : \infty b : \infty c)$; because it is supposed to be derived from the octahedrons $(a : nb : pc)$, which have the secondary axis a, whilst the axes nb and pc are supposed to have become infinite.

§ 26. The most simple of the compound forms of this system are the following:—

Fig. 79 represents a combination of the entire primitive octahedron o, o', $(a : b : c)$ with the principal vertical prism g, $(a : b : \infty c)$.

Fig. 80 is a combination of the entire principal octahedron o, o', $(a : b : c)$ with the principal vertical prism g, $(a : b : \infty c)$ and with the terminal faces b, $(\infty a : b : \infty c)$ parallel to the axes a and c.

Fig. 81 represents a combination of the oblique prism o, o', anterior to the principal octahedron

($a : b : c$) with its vertical prism g, ($a : b : \infty c$) and with the terminal face b, ($\infty a : b : \infty c$).

Fig. 79.

Fig. 80.

Fig. 81.

Fig. 82.

Fig. 82 exhibits a combination which is composed of the oblique prism o' posterior to the principal octahedron ($a : b : c$), its principal vertical prism g, ($a : b : \infty c$), and the three systems of faces parallel to the axes, *i. e.* the terminal face b parallel to the axes a and c, the formula for which is ($\infty a : b : \infty c$); the terminal face a parallel to the axes b and c, which is denoted by ($a : \infty b : \infty c$); and lastly an oblique face d.

Triclinic

VI. SIXTH SYSTEM OF CRYSTALS.

§ 35. The forms belonging to the sixth crystalline system have three dissimilar axes, which are oblique to each other, and in all possible relations as regards length; the choice of the principal axis is perfectly arbitrary. As a result of the obliquity and inequality of the axes, the faces of the forms belonging to this system are not symmetrical, and no other faces are similar but those which are parallel.

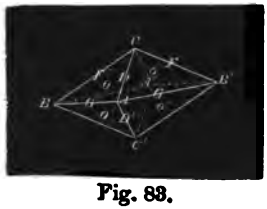
Fig. 83.

Fig. 83 represents an octahedron belonging to this system; the only equal faces are those

which are parallel to each other, so that there are four kinds of faces.

The edges are of six kinds; the anterior terminal edge D is of a different kind to the posterior edge D′; the terminal edge F on the right differs from the terminal edge on the left F′; the right hand lateral edge G is not of the same kind as the left hand lateral edge G′.

The angles are of three kinds, and are formed by the unequal edges.

Sections through the terminal edges, or through the lateral edges, are parallelograms.

When the same substance presents several octahedrons, any one may be chosen as the primitive form, and this is then represented by the formula $(a : b : c)$; but in order to define it completely, the values of the angles α, β, γ formed by the oblique axes with each other must also be denoted.

If the axes of the other octahedrons of the same substance are subsequently determined, it will be found that their axes always form with each other the *same angles* α, β, γ, and that their absolute lengths present very simple numerical relations with those of the corresponding axes of the primitive octahedron; so that all these octahedrons may be represented by the formula

$$(ma : nb : pc);$$

m, n, and p being rational numbers, and generally very simple.

The octahedrons of this system present four different couples of parallel faces, they can enter into combina-

tions, as a single isolated couple or several couples at once. It will often be found of use to be able to distinguish each of these couples by a separate formula. This can easily be done if the letters a, b, c are reserved for designating those halves of the axes on which the positive co-ordinates are usually calculated in analytical geometry, and if, on the contrary, the letters a', b', c' are applied to those portions of the axes which are situated in the direction of the negative co-ordinates. We can then represent

The face AB′C and its parallel by $(a : b : c)$
The face ABC and its parallel by $(a' : b : c)$
The face A′BC and its parallel by $(a' : b' : c)$
The face A′B′C and its parallel by $(a : b' : c)$

The limiting forms in this system are obtained by making successively $p = \infty$, $n = \infty$, $m = \infty$,

or $p = 0$, $n = 0$, $m = 0$.

In this manner three systems of prisms are obtained:

Vertical prisms, the faces of which are parallel to the principal axis C;

Inclined prisms, with their faces parallel to the axis b;

Inclined prisms, with their faces parallel to the axis c;

and three terminal faces parallel to each of the three systems of oblique axes taken two and two.

The crystals belonging to this system are often very complicated and are difficultly defined in a complete manner, because the octahedrons and the prisms most frequently enter into the combinations with one couple only of their faces.

Fig. 84 represents one of these combinations; it contains:—

Fig. 84.

1st. The face on the left of the principal octahedron *o*;

2nd. The oblique terminal face $2d'$;

3rd. The faces on the right and left of the vertical prism *g* and *g'* of the principal octahedron.

4th. The terminal face *a* parallel to the axes *a* and *c*.

5th. The terminal face *c* parallel to the axes *a*, *b*.

The sixth system of crystals comprises a much smaller number of crystallized bodies than the five systems which precede it. The forms of this system may generally be easily recognised by their want of symmetry. The precise definition, however, of their faces is often attended with great difficulty.

DETERMINATION OF A CRYSTAL.

§ 28. We have now to develop the methods by which we are enabled to determine in a rigorous manner the crystalline form of any given crystal. An attentive examination of the crystal and of the symmetry of its modifications is generally sufficient for recognising the system of crystals to which it belongs. This superficial determination is enough when the crystal belongs to the regular system, and it is only necessary to indicate what kind of simple forms enter into its constitution. This, however, is not the case with all the other systems. With these it does not suffice to indicate by name the simple forms of which the crystal is

composed: it is, then, necessary to determine rigorously the values of the angles which the axes form with each other, when these axes are not at right angles, as well as the relations of length of these axes, and this must be done for each of the simple forms of which the crystal is composed. The angles formed by the axes, and the relations of length of the latter, cannot be directly measured on the crystal. The only element which is capable of direct measurement, is the inclination of the various faces, the one upon the other. But it is evident that the angles formed by the axes and the relations of length of the latter are in immediate geometrical relation to the various inclinations of the faces, and that when the latter are known, the determination of the angles formed by the axes and the relative lengths of the latter becomes a simple geometrical problem.

The limits of this treatise do not admit of our demonstrating the method of calculation employed for arriving at this result. The calculation is very simple for the rectangular systems, but it becomes very complicated for the oblique systems. We refer the reader, who is desirous of becoming acquainted with these calculations, to the *Traité de Minéralogie*, by M. Dufrénoy, where he will find a large number of numerical examples of the determinations of crystals, or to the *Crystallography* of Professor Miller, in which general formulæ, applicable to these calculations, are given, which formulæ are remarkable for their great symmetry, and are easily applied to all particular cases that may present themselves.

In order to obtain a rigorous definition of a crystal,

it is not always essential to measure all its dihedral angles. It often suffices to determine the values of a small number of its angles, for instance, when the crystal belongs to one of the more simple crystalline systems. But it is convenient, in every case, to measure as many of the angles as possible. When several of these angles are unnecessary for the determination of the elements of the crystal, they can be employed to verify these elements, and to correct them as occasion may require; all the angles of a crystal are necessarily in geometrical relation with the lengths and the directions of its axes.

The chemist, who is desirous of defining a crystal in an accurate manner, should endeavour to measure all the dihedral angles with the greatest possible care, to note their values, taking care to accord them their proper names. He will then be enabled at any future period, by means of these given data, to determine the elements of the crystal, that is to say, the inclination of the axes and their relations of length.

The essential operations, therefore, in determining the crystalline form of any substance, is the correct measurement of the inclination of the faces towards each other. The instruments used for this purpose are called *goniometers*. Two kinds of goniometers are in use, the common or *contact goniometer* and the *reflective goniometer*.

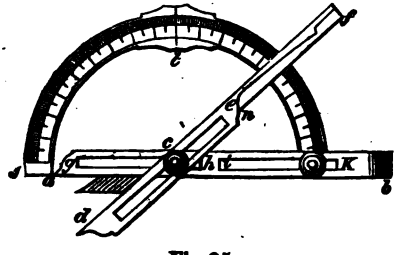

Fig 85.

The contact goniometer, (fig. 85), con-

sists of a graduated semi-circle, on which two metallic cross-blades are fixed; one of these cross-blades *ab*, is fixed at the zero of the division, the other *df*, is moveable, and denotes on the circle the angle of the crystal. In order to measure a dihedral angle, one of its faces is applied to the fixed cross-blade *ab*, in such a manner, that the edge of the angle is perpendicular to the plane of the circle; the moveable cross-blade is then adjusted until its prolongation rests upon the other face of the angle; it is evident that the angle comprised between the two cross-blades, and which is directly indicated on the circle, is the measure of the angle sought.

The two cross-blades *ad*, *df* slide in the grooves *ik*, *gh*, *lm*, so as to admit of the ends *ca* and *cd* being made as short as is required. This condition is indispensable, as it is often necessary to measure very small crystals, which can only be introduced easily between the two cross-blades, when their free ends can be very much shortened.

This goniometer is only capable of affording an approximative value for the angle under examination; it is often difficultly applied to artificial crystals, as these have generally a slight degree of hardness, and are easily broken or distorted by the least pressure.

The reflective goniometer affords much more accurate results; but is only applicable to crystals which present a certain degree of lustre. A great variety of these goniometers have been constructed; we shall describe that which is most generally used, and which is known as *Wollaston's goniometer*.

Wollaston's goniometer (fig. 86) is constructed with

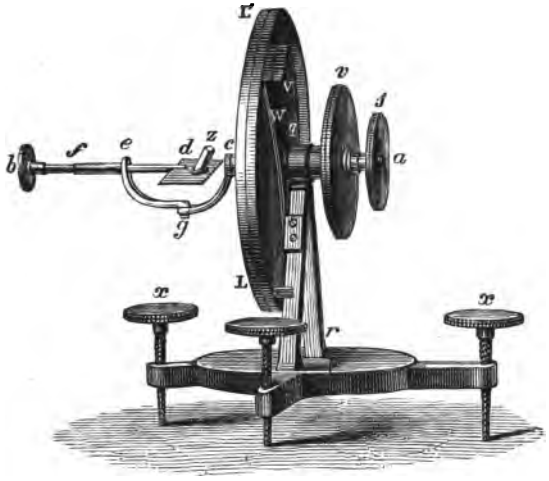

Fig. 86.

a vertical circle LL′ graduated on its edge, the horizontal axis of which is mounted upon a support *pqr*. The circle is turned by means of the disc *v*. A vernier *vw*, placed at the extremity of an arm fixed immoveably upon the stand *pq*, admits of the angle through which the circle has passed being accurately noted.

The axis which carries the circle is hollow; it is traversed by an interior moveable axis *ac*, which is made to turn by the disc *s*. At the extremity *c* of the axis *ac*, a jointed appendage *cgeb* is fixed, which serves to support the crystal *x*. This piece is susceptible of several motions, which assist very much in placing the crystal. It consists of a semi-circle *cge*, articulated at *g*, which carries at its extremity a hollow cylinder *ef*, cast so as to form a screw. This cylinder is traversed by a rod *bd*, which is made to turn by means of a button *b*. The rod *bd* is cleft at *d*; into this slit a thin piece of brass is introduced, upon

which the crystal is fixed by means of a little soft wax.

The crystal is thus placed upon the interior moveable axis *ac*; it can be turned without moving the circle by means of the disc *s*, or with the circle *b*, by means of the disc *v*. The moveable portions of the support *cgeba* admit, without touching the crystal, of its being approached to or removed from the circle, and of various inclinations being given to it. This mobility is necessary, for we shall see that it is essential to the measurement of the dihedral angle of a crystal that the edge of the angle is capable of being placed in a direction rigorously parallel with the axis of rotation of the circle.

The instrument, thus arranged, is placed upon a table, in front of a house which presents several distinctly traced horizontal lines; two of these horizontal lines are chosen as fixed points or marks.

The higher edge of the roof answers perfectly for the higher mark. For the inferior line, the horizontal edge of a window on the ground floor may be taken.

The circle is first adjusted in a perfectly vertical position, which is easily done by means of the screws *xxx*, upon which the foot of the instrument is supported, and by a spirit-level. The circle is disposed, at the same time, in such a manner, as to be perfectly perpendicular to the plane of the house, and, consequently, to the two lines which serve as marks. The crystal is then fixed upon its support by soft wax, in such a manner that the edge of the angle to be measured is nearly at right angles to the plane of the

circle. This must be subsequently adjusted, so as to be rigorously perpendicular to that plane. With this object in view, the eye is brought close to the crystal, so as to receive an image of the lower line in the direction of the crystal. The interior axis *ac* is turned, until the eye, maintaining an invariable position, observes the image of the upper line reflected upon one of the faces of the crystal. The direction of this reflected image ought to be rigorously parallel with the inferior line seen directly. If this condition is not fulfilled, the crystal is moved by means of the fine movements, of which the various pieces of the support are capable. One of the faces of the angle is then perpendicular to the plane of the circle. The edge of the angle will itself be perpendicular to the circle, if the second face fulfils the same conditions as the first. This is ascertained by trying the second face in the same manner as was pursued with the first, whilst the eye is constantly kept in the same position. Some few trials are requisite, in order to make sure of these two conditions; but, with a little practice, their acquirement is rendered very easy.

The crystal being properly placed, the angle is next measured. With this object the circle is turned to the zero point on the vernier by means of the wheel *v*; the crystal is then brought into the position in which the eye perceives the image of the line reflected upon one of the faces of the crystal immediately above the second line seen directly. For this purpose the disc *s* is turned, which does not alter the position of the circle. By means of the wheel *v* the circle is now made to revolve, and, necessarily, carries with it the

interior axis *ac*, and, consequently, the crystal, until the eye, which must never move from its position, perceives the upper line reflected from the second face of the crystal coinciding with the lower line. The angle through which the circle has been turned, and which is measured with the aid of the fixed vernier *vw*, is the supplement to the angle of the crystal.

Supposing *abc* to be the position of the dihedral angle when the eye of the observer *o* perceives the image of the upper lines S reflected on the face of the crystal *ab*, coinciding with the lower line M seen directly. It is evident that, to enable the eye to perceive the same effect upon the second face *ac* of the angle, it is necessary that the dihedral angle should occupy the position *ac'b'*, that is to say, the face *ac* must be made to describe the arc *mnp*, which is precisely the supplement of the angle sought.

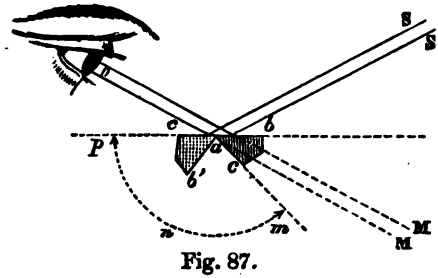

Fig. 87.

The reflective goniometer admits of very accurate measurement of the angles of a crystal, when the faces of the crystal are perfectly lustrous. The most essential condition, after the proper placing of the crystal, is that the eye should preserve a very constant position, particularly if the lines are not situated at a considerable distance from each other. An attempt has been made to perfect the apparatus by adapting a telescope to it, which gives an invariable direction to the visual ray, and which, consequently, admits of the second

line being suppressed. The focus of the telescope ought to be so regulated as to show the upper line distinctly when the telescope is directed towards it. But this arrangement can only be employed with crystals which possess a strong reflective power. Unfortunately this property is only common to a small number of crystals. Some crystals exhibit so imperfect a reflective power as to prevent the edge of a distant house-roof being employed as the upper line. In this case the instrument is placed before an open window, the upper edge of which is open to the sky, and this edge is taken as the upper line. As the lower mark, a black line traced upon a sheet of paper upon the same table with the instrument, or a stretched white thread upon a black ground, may be used; it is necessary, in this case, to make sure that these lines are perfectly parallel with the edges of the window. With some crystals even this arrangement is not satisfactory, on account of their faces being so little reflective. It is possible, however, sometimes to measure the angles of these crystals, but with less accuracy, by placing oneself in a dark room. In this case the light from a candle placed at a certain height, and at some little distance from the goniometer, is used for the upper line, and a black line traced upon paper and illumined by a lamp placed for the purpose behind the observer as the lower line. During the slow motion of the crystal, at the moment the light from the candle, imperfectly reflected from the faces of the crystal, penetrates the eye, a sudden gleam of light is perceived, which enables the observation to be made. In other cases the height of the flame may be limited by a screen.

The errors are thus diminished, which arise from the angle, always rather considerable, at which the observer perceives the height of the flame, when it is not very distant.

Lastly, the reflective goniometer may even be used for crystals which do not distinctly reflect the light, but the faces of which are sufficiently even, by attaching small very thin laminæ of mica to them by means of a liquid. This liquid may be water or spirits of turpentine, according to the nature of the crystal. If this latter means is not applicable, recourse must then be had to the common applying goniometer.

OF THE IMPERFECTIONS OCCURRING IN NATURAL AND ARTIFICIAL CRYSTALS.

§ 29. The crystalline forms which we have just been studying are always entire, and exhibit perfect regularity; but a similar degree of perfection rarely occurs amongst natural crystals, or amongst those obtained in the laboratory. In general, these latter crystals are not regularly terminated throughout; one of their extremities is often entangled and lost amongst other individuals. Certain faces of the same simple form are also frequently much more developed than others, and these latter appear to have been formed under circumstances which did not admit of their natural growth.

This unequal development of the several faces of the same simple form often so completely alters the general appearance of the crystal, that it requires great practice in order to recognise its real form, more particularly

when the crystal belongs to one of the latter systems of crystals. But in the midst of these anomalous extensions of the faces, their respective directions remain rigorously constant; and if the angles of the crystal are measured with care, it is easy to construct the regular figure upon paper, or, as it is termed, the *type*, which corresponds to the imperfect crystal. For this purpose it is only necessary, in preserving for the various faces of the crystal the directions obtained by the measurement of the angles, to place all the faces of the same kind at equal distances from the face of the crystal.

We will now give some examples of these irregularly developed crystals; they are found in all the different systems, even in the regular system.

The perfect form, the regular octahedron (fig. 88), is

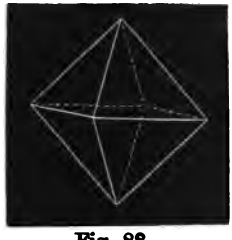

Fig. 88.

that which alum commonly assumes; but alum only affects this form in very small crystals which have been freely developed in the middle of a solution, for instance, those which form at the end of a fine thread suspended in the liquid. Sometimes a very small perfectly regular crystal is formed on the surface of a large crystal, to which it is only attached by one of its edges or angles.

The crystals which are developed at the side of a vessel are always enveloped the one in the other, and only exhibit some of their free faces, or even only portions of their faces. Fig. 89 gives an idea of the general form of these crystals. The figure is an exact copy of a group of alum crystals found in one of the large vats

employed for crystallizing the alum used in the arts. If a small regular crystal of alum is placed in a vessel filled with a solution of that substance saturated

Fig. 89.

in the cold, the crystal gradually becomes larger, but its development is very different, according to the position in which it is placed in the vessel. If the crystal is placed at the bottom of the vessel, and nearly on its axis, all its faces generally increase in a regular manner, with the exception of those which are in contact with the vessel. The crystal generally increases more in a horizontal than in a vertical direction, and

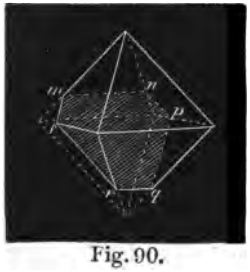

Fig. 90.

presents an appearance analogous to that represented in fig. 90. The irregular face *mnpqrs* is that which rests upon the bottom of the vessel. It will be seen that this face is precisely that which would have been obtained by detaching

from a regular octahedron a more or less thick slice parallel to one of its faces.

Sometimes the crystal assumes the form shewn in fig. 91; the growth of the crystal, perpendicularly to the horizontal faces, has been almost nothing, or at least very much less than in the other directions, and the two faces which were horizontal in the solution, exhibit similar forms. When the crystal is placed at the bottom of the vessel, and very near to the lateral sides, its development is restricted in a greater number of directions, and its exterior form becomes still more irregular.

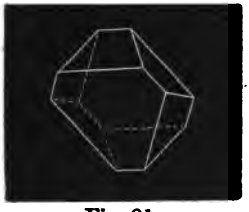

Fig. 91.

Very large crystals of alum, regularly developed in every sense, may, however, be obtained artificially. A small regular crystal must be placed, for this purpose, at the bottom of a vessel containing a solution of alum saturated in the cold, and must be turned every day, so as to rest upon a different face. If care is taken that each face rests in its turn on the bottom of the vessel, the crystal will grow in a perfectly regular manner, and may acquire considerable size without losing any of its primitive regularity. In most cases, however, this regularity is only apparent. A large crystal developed under these circumstances, or which is said to have been grown, is seldom transparent. Its faces are nearly always more or less undulated, and the optical examination of the crystal exhibits the existence of a number of imperfections in its interior.

The smallest crystals are generally the most perfect; and these should always be chosen for measuring the

angles. The determination of their angles, by means of Wollaston's goniometer, is also more exact, because the slight variations of position to which the eye of the observer is subject, then only exert a very feeble influence.

Fig. 92 represents a combination of the octahedron with the hexahedron, which frequently occurs in sulphuret of lead or galena. But the mineral is as frequently found in the form represented in fig. 93. Its exterior aspect appears at first sight to belong to a crystal of the second system, that is, to the system of the octahedron with a square base; but if the dihedral angles of the crystal are measured, it is soon found that the faces *o* belong to a regular octahedron. Fig. 93 differs from fig. 92, in as much as in the former the vertical faces of the hexhahedron are extraordinarily developed.

Fig. 92.

Fig. 93.

Substances crystallizing in regular octahedrons, occur sometimes in the form shown in fig. 94, which is called the *cuneiform octahedron.* It will easily be recognized, by measuring the angles, that the faces of the crystal belong to a regular octahedron; but four of these faces have received an abnormal development. In the third system of crystals, or the

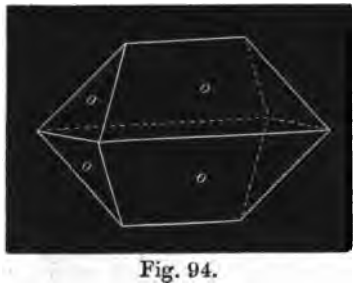

Fig. 94.

rhombohedral system, many anomalies of the same kind occur.

Carbonate of lime crystalizes in the form of a rhombohedron, the angle of which is 105° 5′ (fig. 95); it has been stated (§ 4) that this mineral presents cleavages with the greatest ease in three directions, parallel to the faces of the rhombohedron; it follows from this, that a great number of solids of cleavage may be obtained (fig. 96) possessing the same angles in every case, but exhibiting very different aspects. The direction of the principal axis in these rhombohedral fragments is always parallel to the line that forms equal angles with the three equal sides which converge towards the same summit.

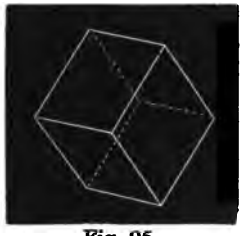

Fig. 95.

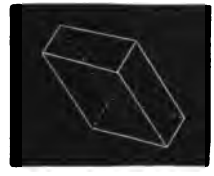

Fig. 96.

The ordinary form of quartz is a regular six-sided prism, terminated by an hexagonal dodecahedron. The dihedral angles of the prism measure 120° and the dihedral angles of two consecutive faces of the dodecahedron are = 133° 40′. Fig. 97 represents the perfect type of

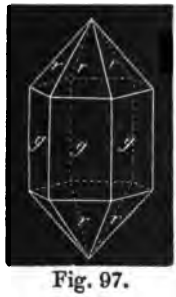

Fig. 97.

Fig. 98.

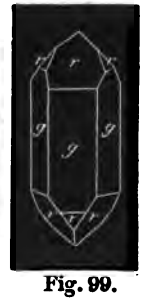

Fig. 99.

Fig. 100.

this form; but it is very rare that the crystals of quartz present a similar regularity. Figs. 98, 99, 100 represent some natural crystals of quartz. They are modifications of the type (97) produced by the abnormal development which certain faces have received during crystallization. If the angles of these different crystals are measured, it will always be found that the dihedral angles of the faces of the vertical prism are $= 120°$, and that the consecutive faces of the pyramids form with each other angles of 133° 40′.

Irregularities of the same kind occur in the more complex crystalline systems; they sometimes change the aspect of the crystal so completely, that it requires long habit to enable one to recognize the nature of the different faces. In most cases it is necessary to have recourse to the direct measurement of the dihedral angles. An idea of the changes which the same form may undergo may be gained by comparing the two figures 101 and 102, which represent two crystals of felspar belonging to the fifth system, and which possess exactly the same faces very differently developed.

Fig. 101.

Fig. 102.

GROUPING OF CRYSTALS, TRANSPOSITIONS AND HEMITROPISM.

§ 30. It has already been stated that crystals never exhibit rentrant angles, and that angles of this kind

are only observed as a consequence of the juncture of two individual crystals. This juncture is sometimes effected with a certain degree of symmetry, and the group of crystals then present a regular aspect, as will be seen by the instances shown in figs. 103 and 104.

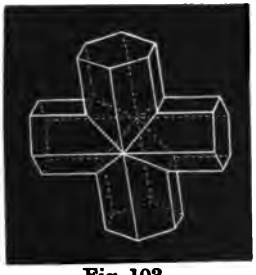

Fig. 103.

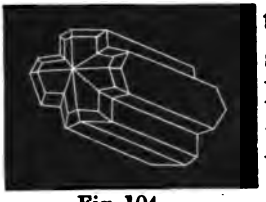

Fig. 104.

In these cases the juncture of the crystals is easily recognised; but instances sometimes occur in which the juncture is less apparent. Thus the crystalline form represented in fig. 105 is sometimes met with. If we examine separately each half of the crystal produced by the plane passing through the edges of the rentrant angle, we shall soon perceive that each half belongs to a regular octahedron, and that the form represented by fig. 105 may be obtained by cutting the regular octahedron (fig. 106) into two equal parts by a plane *mnpqrs* parallel to the faces of the octahedron and turning one of the halves of the octahedron 60° on the face of separation. One of the halves of the octahedron is then said to be *transposed*.

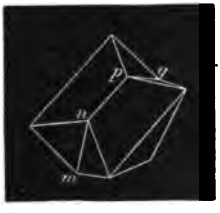

Fig. 105.

Fig. 106.

Fig. 107 represents a very common form of native sulphate of lime or gypsum; it is obtained by cutting

the figure 108 into two equal parts through the plane *omnpqr*, and by turning one of the halves half a revolution with reference to the other. *Hemitropism* is then said to have occurred, and the crystal represented in fig. 107 is called a *hemitrope crystal*.

Fig. 107.

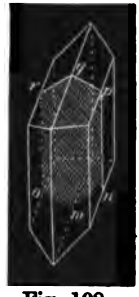

Fig. 108.

DIMORPHISM AND POLYMORPHISM.

§ 31. It was long supposed that the same body could only affect the crystalline forms derived from a single primitive form in the manner we have demonstrated in the preceding paragraphs. It is, however, now known that this is not the case. Thus, carbonate of lime generally crystallizes in forms of the rhombohedric system, and all its crystals yield a solid rhombohedron by cleavage of 105° 5′. But carbonate of lime has also been found in forms belonging to the fourth system of crystals, which are quite incompatible with rhombohedral cleavages. Mineralogists have called this variety *arroganite*.

Sulphur, crystallized from a state of fusion, assumes the form of lengthened oblique prisms with a rhombic base, which belong to the fifth system of crystals. The same substance deposited in the crystalline state from solution in sulphuret of carbon assumes the form of a right octahedron with rhombic base, which belongs to the fourth system. Native crystals of sulphur also occur in the latter form.

Substances which are thus capable of crystallizing in two different systems are called *dimorphus substances;* the phenomenon itself is styled *dimorphism.*

The crystals of the same substance which belong to two different systems are not only dissimilar in their exterior forms, but they also differ in many other respects, and these differences are even manifested when they are reduced to the finest possible powder by mechanical agency. Their hardness and density are thus different; they often comport themselves differently when exposed to heat or under the influence of chemical agents.

The same substance never crystallizes in forms belonging to different systems, except when crystallization occurs under very different circumstances, as, for instance, at temperatures very distant from each other.

We are led to admit that the forces which are active in causing the molecules to group themselves in the form of crystals are variable in their nature and intensity, according to the temperature; so that the molecules which have been grouped together at a high temperature will be under the influence of very different forces from those which obtained at the time of their crystallization, when the body cools down to the ordinary temperature. It is, also, often remarked that crystals which have been formed at high temperatures, and which were perfectly transparent at the moment of their production, become opaque and pulverulent after a short time. Disaggregation ensues, because the molecules have a tendency to arrange themselves differently, in accordance with the forces which prevail, at less elevated temperatures. It is often possible,

when this alteration has occurred, to distinguish, with the aid of a magnifier, that the mass is formed of small rudimentary crystals, possessing the form which the substance affects at ordinary temperatures.

The transformation is very obvious in the crystals of sulphur obtained by fusion. These crystals are in the form of very elongated prisms belonging to the fifth system; they are of a clear yellow colour, perfectly transparent, and somewhat flexible. At the ordinary temperature the aspect of these crystals is completely changed at the expiration of a few days; they lose their transparency, become friable, and if their powder is examined under the microscope, it will be observed that it is composed of small crystals belonging to the fourth crystalline system, and which are similar to those which sulphur forms when it crystallizes at common temperatures from solution in sulphuret of carbon. So that the crystals present externally the forms of the fifth system, whilst their interior possesses the crystalline texture and the cleavages of the fourth system.

We know of no substances at present which crystallize in more than two different systems; but it is conceivable that a substance placed under various conditions might assume three, or even a greater number of incompatible forms; the substance would then be called a *polymorphus substance.*

ISOMORPHISM.

§ 32. The crystalline form of a body is not in itself sufficient to define that body. If the body crystallizes in the regular system, it is clear that it will be insuffi-

cient to assert that it affects the form of a regular octahedron, or of a cube, in order to characterize it; as all the octahedrons and hexahedrons of the regular system are identical. A similar difficulty does not exist in the other systems, as the forms bearing the same name and belonging to the same system are very far from being identical. We have, indeed, seen that the same substance can assume the forms of several octahedrons belonging to the same system of crystals, but that all these octahedrons present relations amongst themselves, by the aid of which it is easy to discover that they belong to the same substance. It is sufficient for this purpose to measure the different dihedral angles of the crystal, and to deduce, by calculations, from these measurements, the angles and the relations of length amongst the axes; it will always be found, when the octahedrons belong to the same substance, that the angles of the axes are *rigorously identical* in all these forms, and that the lengths of the homologous axes bear a *rational and very simple relation* to each other. It is thus easily conceived, that, in point of fact, the precise determination of the crystalline form of a body is sufficient to characterize it, when that form does not belong to the regular system of crystals.

There is, however, one circumstance which militates against the proposition we have just put, and which is of the greatest importance to our chemical theories. It has been found that those substances which present a similar chemical composition, affect crystalline forms, which, although not absolutely identical, offer such a marked external resemblance, that they can only be

distinguished from each other by the most accurate measurement of their angles. Thus the carbonate of lime, of magnesia, of protoxide of manganese, of oxide of zinc, all crystallize in rhombohedrons, and present rhombohedral cleavage. The angles of these rhombohedrons are:—

In carbonate of	lime	105° 5′
„	magnesia .	107° 25′
„	manganese	107° 20′
„	iron	107°
„	zinc . . .	107° 40′.

These angles are not sufficiently distinct to be distinguished from each other by simple inspection.

When, moreover, these substances, which assume crystalline forms very little different from each other, are allowed to crystallize together from the same medium, it has been found that they can replace each other in variable proportions. Natural crystals, indeed, occur, into the composition of which two or more of the preceding carbonates enter in variable proportions. These complex crystals always affect the rhombohedral form; the angles of these rhombohedrons are intermediate between those of the rhombohedrons of the simple carbonates of which they are composed; they approximate most nearly to the angles of the rhombohedron which is peculiar to the carbonate that predominates as regards quantity in the crystal. Sulphate of iron and sulphate of copper, dissolved in water, combine with similar quantities of water, and crystallize in identical forms, if the crystallization takes place at the proper temperature. These temperatures

are not absolutely the same for the two salts, but they only differ by a few degrees. If a crystal of sulphate of copper is placed in a solution of sulphate of iron, at a temperature differing very little from that at which the sulphate of iron crystallizes in the same form, it is found that the crystal of sulphate of copper continues to grow in the solution, by assimilating the molecules of sulphate of iron.

The crystal placed again in a solution of sulphate of copper, is augmented in size by the addition of molecules of sulphate of copper; so that a complex crystal may be obtained, produced by alternate layers of sulphate of copper and sulphate of iron. These layers are easily distinguished, on breaking the crystal, by their different tints of colour.

If solutions of sulphate of iron and of sulphate of copper are mixed, and the liquid is submitted to slow evaporation, crystals are obtained which are composed at once of sulphate of iron and sulphate of copper. These crystals affect the form of sulphate of copper with some slight differences in the angles.

The proportions of the two sulphates may, however, be varied without limit, according to the respective quantities which have entered into the primitive mixture. Substances which partake of the property of thus crystallizing in forms belonging to the same system of crystals, and which present but slight differences in the absolute values of their angles, and which, morever, are *capable of replacing each other in variable proportions,* whilst forming always similar crystals, are called *isomorphus substances*, and the phenomenon itself is called *isomorphism.*

It has been stated that isomorphus substances always exhibit a similar chemical composition; but it is not always easy to crystallize in the same form those substances which exhibit a similar chemical composition. Thus carbonate of magnesia and carbonate of protoxide of iron occur crystallized in nearly identical rhombohedrons; they possess a similar chemical constitution; one might suppose that it would consequently be also easy to obtain sulphate of magnesia and sulphate of iron, which have a similar chemical constitution, in the same crystalline form. If, however, solutions of these two salts are mixed, and the liquid is evaporated, the two sulphates do not crystallize together, they crystallize separately in forms belonging to different systems. If the two kinds of crystals are submitted to analysis, it will be found that they do not contain similar quantities of water. The sulphates of iron and of magnesia, in crystallizing from the same solution, combine with different quantities of water, and, consequently, do not present a similar chemical composition, and it is, therefore, not surprising that they should assume very different crystalline forms. The instance which we have just cited, however, does not prove that sulphate of iron and sulphate of magnesia are not isomorphus.

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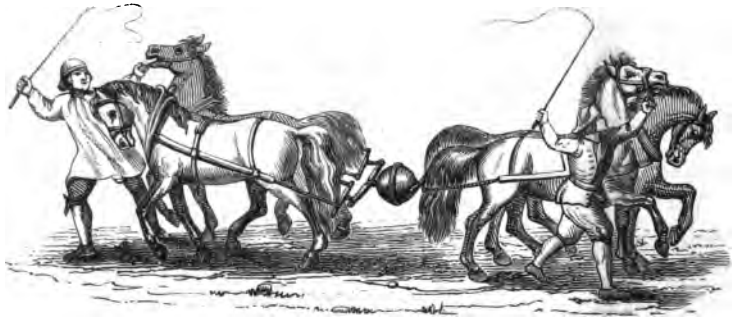

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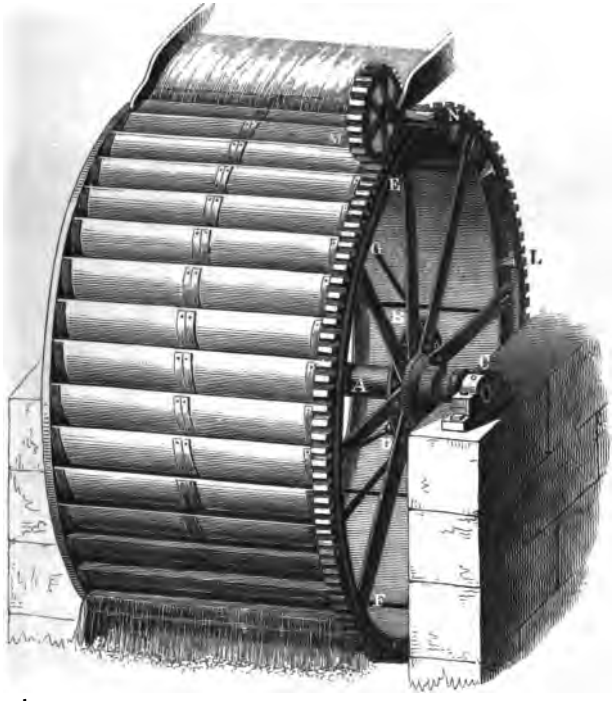

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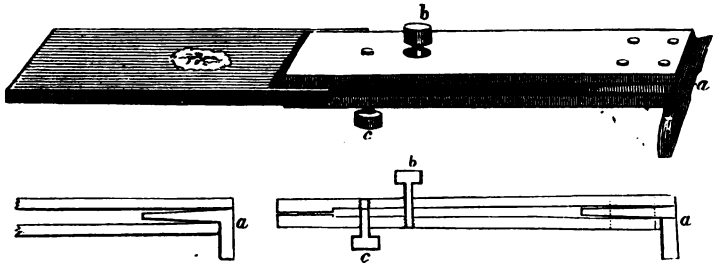

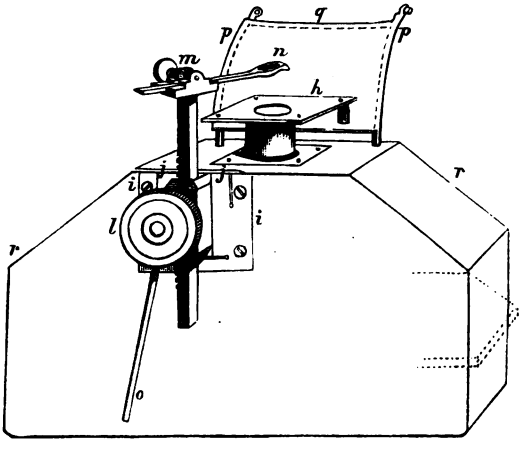

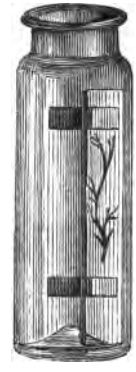

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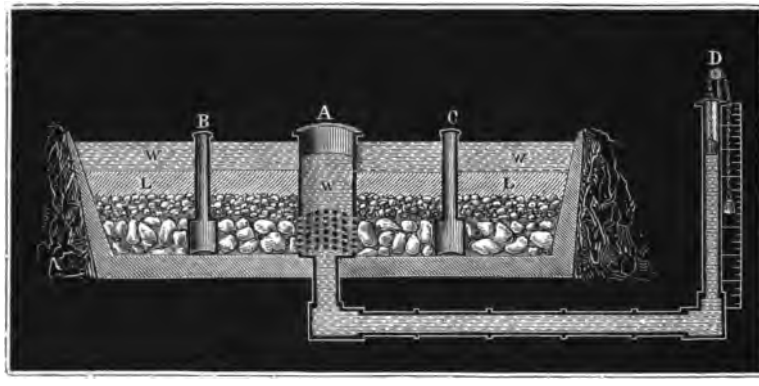

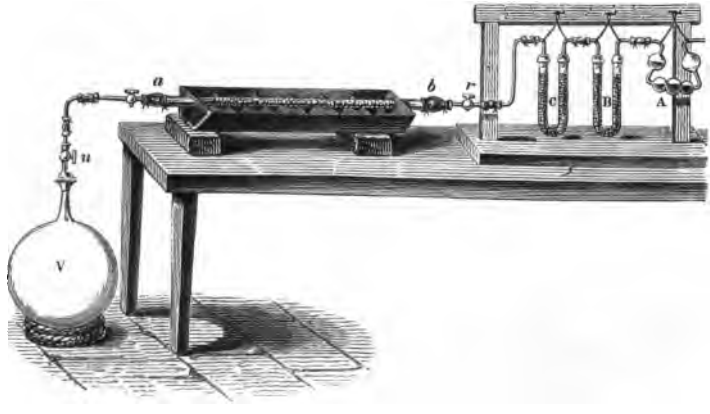

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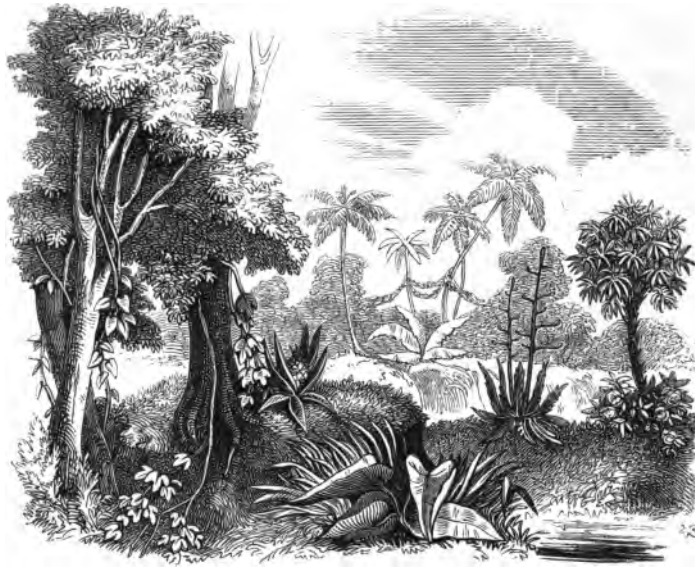

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